EMISSIONS FROM AN ELECTRICAL POWER GENERATING UNIT (MOSS LANDING UNIT #1)

Source Test Report

for the

2000 CENTRAL CALIFORNIA OZONE STUDY

May 28, 2002

Prepared for:
San Joaquin Valley Air Pollution Study Agency
Attn: Don McNerny, Chief
Modeling & Meteorology Branch
Planning & Technical Support Division
California Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Prepared by:

University of California, Riverside
Bourns College of Engineering
Center for Environmental Research and Technology

Table of Contents

BACKGROUND

The University of California, Riverside, Bourns College of Engineering - Center for Environmental Research and Technology (CE-CERT) has conducted the following emissions testing and analyses:

Report No: 02-AP-20934-006-DFR

For: 2000 Central California Ozone Study

Purpose: To assess a variety of emissions from a power generating unit.

Tested At: Moss Landing, CA

Test Date: October 7, 2000

Draft Report: May 28, 2002

Final Report: Due after receipt of comments and recommendations

Project Staff:

Dennis R. Fitz, Principal Investigator
William A. Welch, Principal Development Engineer
Kathleen Cocker, Associate Development Engineer
C. Anthony Taliaferro, Development Technician V
David Valdez, Laboratory Assistant

1.0 INTRODUCTION

As part of the 2000 Central California Ozone Study, the University of California, Riverside, Bourns College of Engineering–Center for Environmental Research and Technology (CE-CERT) was contracted to perform field testing at up to five stationary gas-fired combustion power generation facilities. CE-CERT was able to complete testing at two of the facilities before the onset of the California energy crisis, which impaired access to additional facilities. This report details the testing conducted at the Southern Energy California Unit #1 in Moss Landing, CA.

Results from the field testing include flow rates, temperatures, and moisture content of effluent streams as well as emissions concentrations and mass flow rates of CO, CO_2, NO, NO_2, PM_{10}, aldehydes and ketones, toxics such as chlorinated hydrocarbons, and C_1-C_4 hydrocarbons.

Based on previously reported emissions results, CE-CERT acquired appropriate calibration gas standards for emissions analyzers and installed them in a field testing vehicle. The portable gaseous emissions analyzer, particulate sampling trains, and integrated gaseous sampling systems were assembled and transported to the site.

Three complete source tests were performed at the Moss Landing facility over the course of one day. Testing included measurements of flow parameters and pollutant emissions concentrations. Measurement methods followed established source testing methods by the U.S. Environmental Protection Agency (EPA), California Air Resources Board (ARB), and the South Coast Air Quality Management District (SCAQMD). For determination of velocities and flow rates, stack traverses were performed with a Pitot tube and thermocouple. PM_{10} and moisture content samples were acquired through traverse sampling using a Method 5-style sampling train. CO and CO_2 emissions concentrations were measured continuously using non-dispersive infrared detection (NDIR). NO, NO_2, and O_2 concentrations were measured continuously using electrochemical detection. Integrated samples were obtained through cartridges for aldehyde determinations, and into Summa® canisters for air toxics determinations. Integrated gaseous samples were drawn into Tedlar® bags for C_1 – C_4 analyses. A set of three complete test runs was performed at the facility. Upon completion of the third run, the PM_{10} samples and integrated bag samples were immediately transported by vehicle to the laboratories for analyses.

This report includes a description of the site and sampling locations, process operating parameters, emissions concentrations, and mass emissions rates.

2.0 SAMPLING AND ANALYTICAL PROCEDURES

2.1Velocity, Moisture, and Flow Determination

Temperatures, velocities, and flow rates in the exhaust duct were determined using ARB Methods 1, 2 and 3.[1] The methods involve using an "S" type Pitot tube and thermocouple assembly to traverse the exhaust duct across a predetermined number of points, taking temperature and differential pressure measurements at each point. Moisture content in the effluent was determined gravimetrically using ARB Method 4.[1] These results are then used in combination with the average gas density and stack cross sectional area to determine exhaust flow rates.

2.2Particulate Matter Method

For determination of total PM_{10}, the exhaust stream was sampled isokinetically following SCAQMD Method 5.1.[2] An integrated sample for each test was acquired over a minimum of 72 minutes. Each sample was extracted from the exhaust duct through a stainless steel nozzle and probe, impingers immersed in an ice bath, and a tared 0.45 micron Gelman quartz fiber filter located downstream of the last impinger. An additional straight tube impinger (empty bubbler) was placed at the front of each sampling train (Figure 1). The sample train was analyzed according to a modified SCAQMD Method 5.1. After sampling, the filter was removed and placed in a desiccator until completely dry. Following drying, the filter was weighed to determine the fraction of sample acquired on the filter. The probe, nozzle, sampling lines, and impingers were washed with deionized water and methylene chloride, and the washing solutions were combined with the impinger solutions. The combined solution was extracted with methylene chloride. The aqueous fraction was heated to boil off water, and the organic fraction was allowed to evaporate at room temperature. Residues from both fractions were weighed and combined with the sample weight from the filter to determine the total particulate sample weight. Samples were stored at 4 ºC until analyzed at the CE-CERT laboratory.

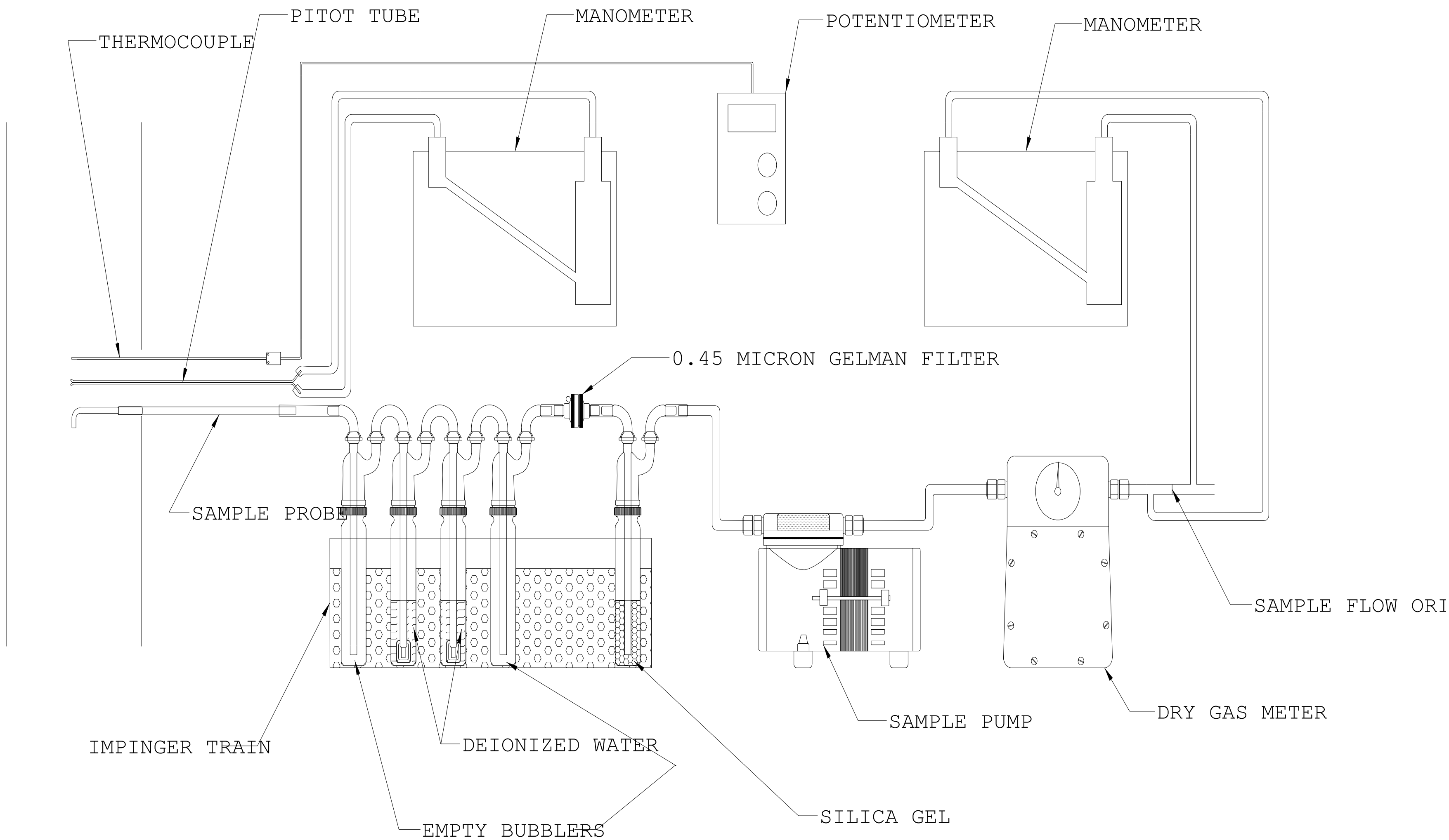

Figure 1. Particulate Matter Sampling System.

2.3Aldehyde Method

A continuous sample was extracted from the exhaust stream through the sample conditioning system shown in Figure 2 during each test run. The conditioning system consisted of a miniature sampling train, including a single in-stack nozzle (facing downstream), a stainless steel probe, empty mini-impingers (for moisture knockout) in an ice bath, and a 0.45 micron pore size Gelman paper filter. The sample stream was drawn through the conditioning system and a cartridges containing crystalline 2,4-dinitrophenylhydrazine (DNPH) impregnated on a C-18 sorbent. The sample flow rate was set to approximately 1 liter per minute and measured with a calibrated dry gas meter. Analyses of the cartridges were performed by Performance Analytical according to EPA Compendium Method TO-11A.[3] The DNPH cartridges were extracted with acetonitrile and analyzed for aldehyde and ketone derivatives using high performance liquid chromatography (HPLC). Table 1 shows the compounds that were quantified by this analysis. Mass emissions of individual carbonyl species were determined from analyzed concentrations, sample volume, and effluent volumetric flow rate.

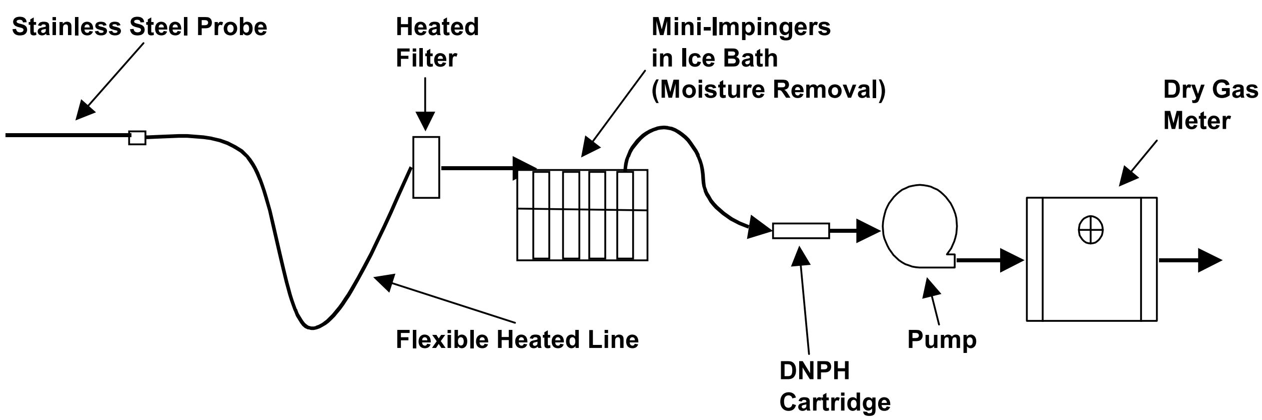

Figure 2. Aldehyde Sampling System.

Table 1. Aldehyde and Ketones Quantified.

Formaldehyde
Acetaldehyde
Acetone
Acrolein
Propionaldehyde
Crotonaldehyde
Butyraldehyde
Benzaldehyde
Isovaleraldehyde
Valeraldehyde
o-Tolualdehyde
m and *p*-Tolualdehyde
Hexaldehyde
2,5-Dimethyl Benzaldehyde

2.4 Air Toxics Method

A continuous sample was extracted from the exhaust stream through the sample conditioning system shown in Figure 3 during each test run. As above, the conditioning system consisted of a miniature sampling train, including a single in-stack nozzle (facing downstream), a stainless steel probe, empty mini-impingers (for moisture knockout) in an ice bath, and a 0.45 micron pore size Gelman paper filter. The sample stream was drawn through the conditioning system and a Teflon pump with Viton valves and O-rings. An evacuated Summa canister was attached downstream of the pump via a "T" connector, allowing for the continuous purge of sample prior to toxics sampling. The canister was equipped with a pre-set flow controller (0.8 liter/hour). The valve was opened, allowing sample into each canister for approximately 1 hour. The Summa canister samples were analyzed by combined gas chromatography/mass spectroscopy (GC/MS) for volatile organic compounds. The analyses were performed by Performance Analytical according to EPA Compendium Method TO-14A,[4] utilizing a direct cryogenic trapping technique. The analytical system comprised a Hewlett-Packard Model 5973 GC/MS/DS interfaced to an Entech 7100 automated whole air inlet system/cryogenic concentrator. A 100% Dimethylpolysiloxane capillary column (RT_x-1, Restek Corporation, Bellefonte, PA) was used to achieve chromatographic separation. Table 2 shows the list of target compounds.

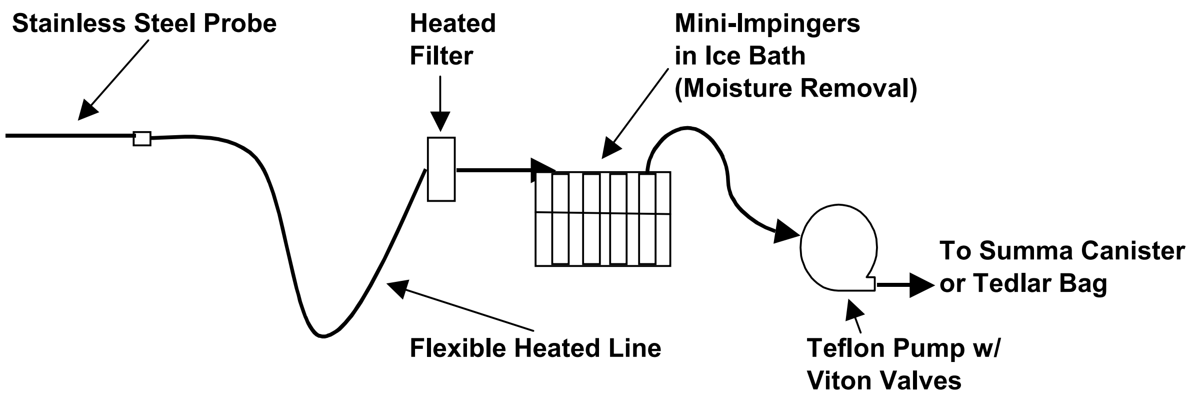

Figure 3. Air Toxics/C_1-C_4 Sampling System.

Table 2. Compounds Identified by TO-14A Analysis.

Chloromethane	Bromodichloromethane
Vinyl Chloride	Trichloroethene
Bromomethane	*cis*-1,3-Dichchloropropene
Chloroethane	4-Methyl-2-Pentanone
Acetone	*trans*-1,3-Dichloropropene
Trichlorofluoromethane	1,1,2-Trichloroethane
1,1-Dichloroethene	Toluene
Methylene Chloride	2-Hexanone
Trichlorotrofluoroethane	Dibromochloromethane
Carbon Disulfide	1,2-Dibromoethane
trans-1,2-Dichloroethene	Tetrachloroethene
1,1-Dichloroethane	Chlorobenzene
Methyl *tert*-Butyl Ether	Ethylbenzene
Vinyl Acetate	*m* & *p*-Xylene
2-Butanone (MEK)	Bromoform
cis-1,2-Dichloroethene	Styrene
Chloroform	*o*-Xylene
1,2-Dichloroethane	1,1,2,2-Tetrachloroethane
1,1,1-Trichloroethane	1,3-Dichlorobenzene
Benzene	1,4-Dichlorobenzene
Carbon Tetrachloride	1,2-Dichlorobenzene
1,2-Dichloromethane	

2.5 Gas Concentration Methods

A Testo model 360 analyzer was used to measure gas concentrations. Carbon monoxide and carbon dioxide concentrations were continuously monitored and recorded using a non-dispersive infrared (NDIR) detector. Nitric oxide, nitrogen dioxide, and oxygen concentrations were continuously monitored and recorded using electrochemical detection cells. The sampling, conditioning, and analyses of CO, CO_2, NO, NO_2, and O_2 followed ARB Method 100. A schematic of the continuous gaseous analyzer system is shown in Figure 4. For C_1-C_4 gas determination, an integrated sample was extracted from the exhaust stream through the sample conditioning system shown in Figure 3 during each test run. A Tedlar bag was attached downstream of the pump via a "T" connector, allowing for the continuous purge of sample prior to gas sampling. The bag valve was opened, allowing sample into the bag over a 4 to 6 minute period. The Tedlar bag samples were analyzed at the CE-CERT laboratory by gas chromatography for C_1 – C_4 organic compounds using the Auto/Oil Standard Conditions.[5] The analyses were performed utilizing a fixed response factor.

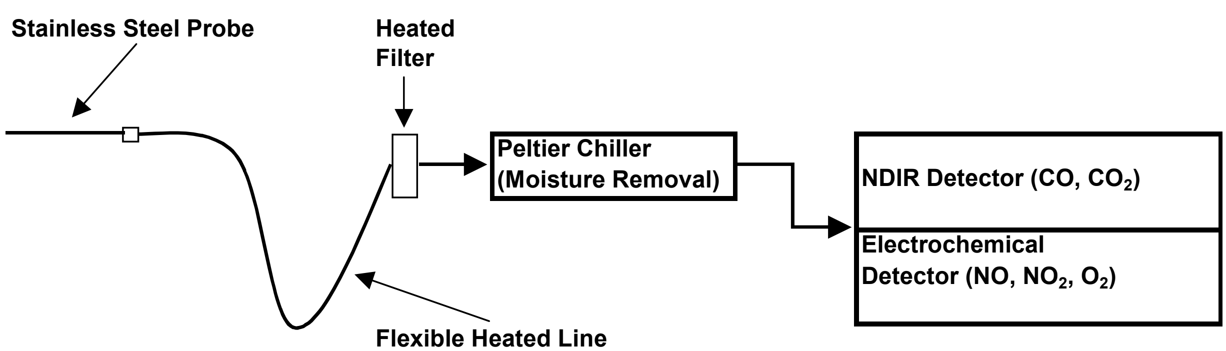

Figure 4. Continuous Gas Sampling System.

3.0 PROCESS DESCRIPTION

The process tested was Unit #1, a natural gas-fired steam turbine used to produce electricity. The unit is owned and operated by Duke Energy Co., and is located in Moss Landing, California. It has a generating capability of 700 MW, and was operating at approximately 80% of capacity during testing.

The exhaust effluent is ducted from the generator building to a large stack enclosure. The bottom of the enclosure houses a water tank reservoir, which rises 50 ft. The exhaust stack enters the enclosure above the reservoir, where it makes a 60-degree turn to vertical. The sampling ports are located approximately 70 ft. above the turn (see Figure 5). The exhaust stack diameter at the sampling location is 30 ft. There are 2 sampling ports, located directly across from each other.

Twelve sample traverse points were selected for testing (6 per port). The location of the sampling points were determined using ARB Methods 1 and 2 (Figure 6).

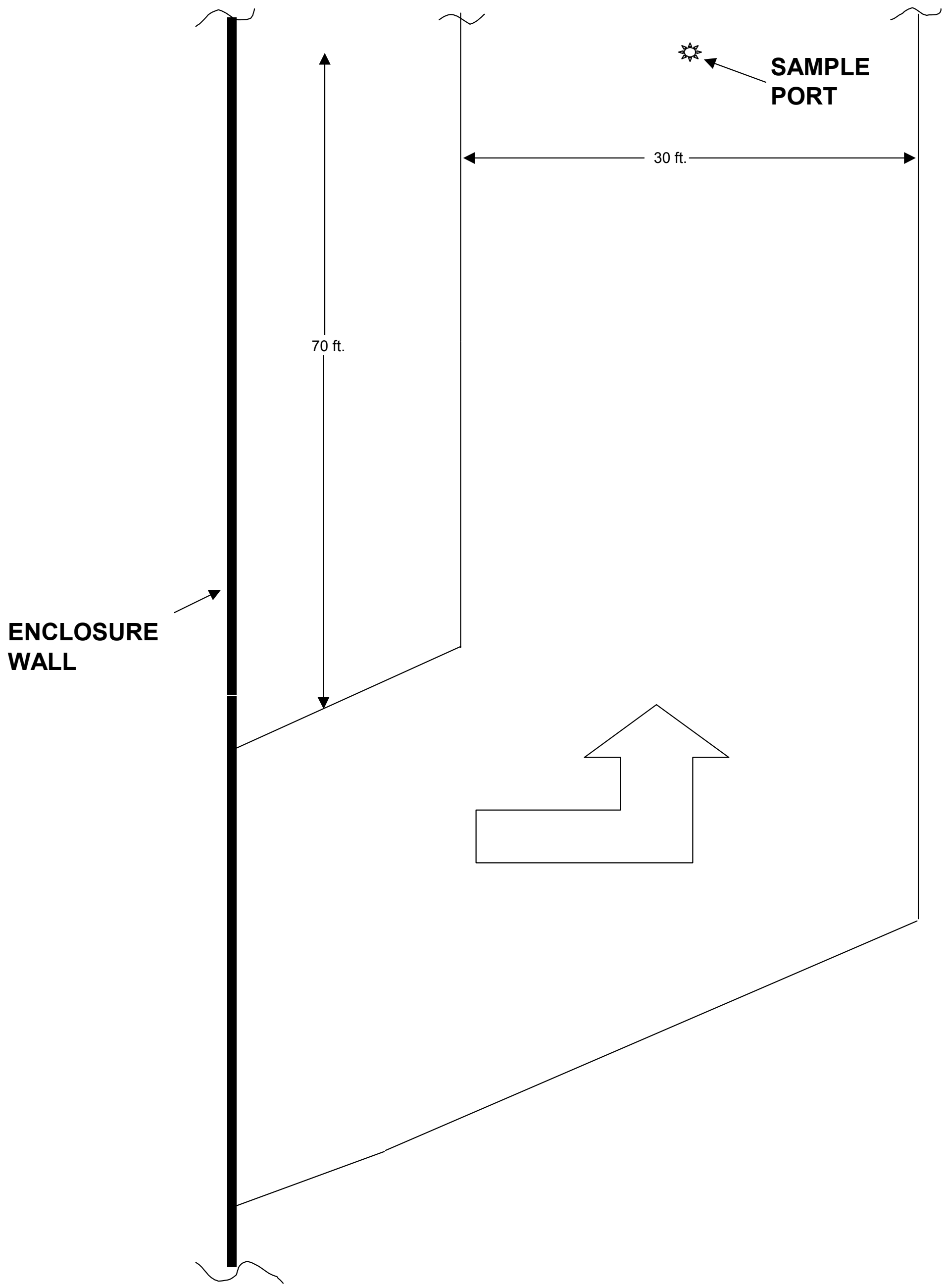

Figure 5. Moss Landing Unit #1 Exhaust Stack (Side View).

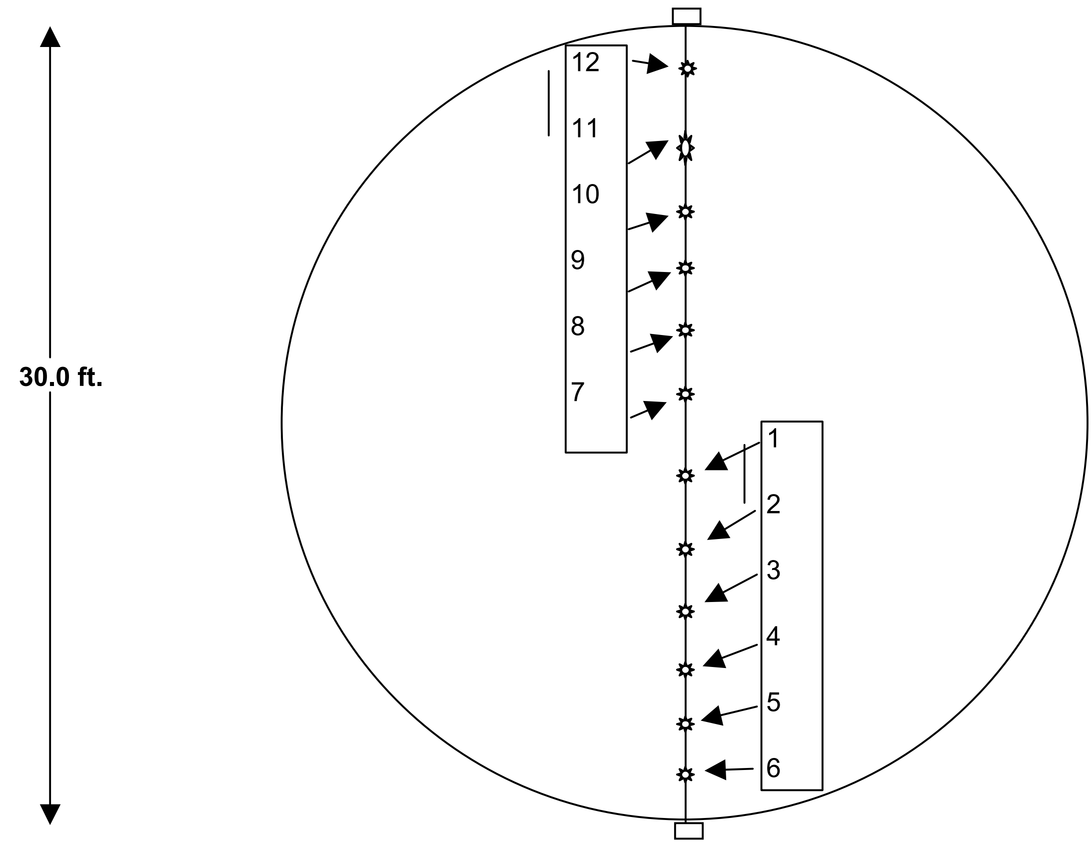

Figure 6. Moss Landing Unit #1 Sample Points (Cross-Section).

4.0 RESULTS

Three identical test runs were performed using the procedures described in Section 2.0. The exhaust flow rates, emission concentrations, and mass emission rates were calculated from the data collected during each run for species that were detected in at least one sample. The appendix includes all analysis data.

Table 3 summarizes the criteria pollutant and fixed gas results for the three test runs, along with the average concentrations and mass flow rates for the entire test period.

Table 3. Criteria Pollutant and Fixed Gas Emissions.

	Concentration (ppm CO, NO, NO_2; %CO_2,O_2)				Calculated Mass Flow Rate (lb/hr)				
Compound Name	run #1	run #2	run #3	AVG	run #1	run #2	run #3	AVG	SD
CO	85.2	82.30	73.45	80.32	321.93	311.62	287.00	306.85	17.95
CO_2	9.65	9.56	9.35	9.52	5.73E+02	5.69E+02	5.74E+02	5.72E+02	2.69E+00
O_2	3.632	4.27	4.57	4.16	1.57E+02	1.85E+02	2.04E+02	1.82E+02	2.38E+01
NO	50.322	44.85	36.21	43.80	203.69	181.92	151.58	179.06	26.17
NO_2	4.32	4.03	2.20	3.52	26.81	25.06	14.09	21.99	6.89
PM_{10}	N/A	N/A	N/A	N/A	14.16	11.16	9.56	11.63	2.33

Table 4 summarizes the aldehyde results for the three test runs, along with the average concentrations and mass flow rates for the entire test period. All concentrations were corrected for the method blank. Acetone was not reported since large amounts were observed on the method blank.

Table 4. Aldehyde Emissions.

	Measured Concentration (ppb)				Calculated Mass Flow Rate (g/hr)				
Compound Name	run #1	run #2	run #3	AVG	run #1	run #2	run #3	AVG	SD
Formaldehyde	38.46	46.50	97.66	60.87	70.73	85.70	185.73	114.05	62.52
Acetaldehyde	221.54	263.83	376.95	287.44	597.66	713.23	1051.62	787.50	235.92
Propionaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzaldehyde	0.00	0.00	2.65	0.88	0.00	0.00	17.81	5.94	10.28
Valeraldehyde	2.03	0.00	0.00	0.68	10.69	0.00	0.00	3.56	6.17

Table 5 summarizes the air toxic results for the three test runs, along with the average concentrations and mass flow rates for the entire test period.

Table 5. Air Toxic Emissions.

	Measured Concentration (ppb)				Calculated Mass Flow Rate (g/hr)				
Compound Name	run #1	run #2	run #3	AVG	run #1	run #2	run #3	AVG	SD
Chloromethane	0.00	0.00	12.00	4.00	0.00	0.00	38.37	12.79	22.15
Acetone	14.50	150.00	140.00	101.50	51.58	534.66	514.96	367.07	273.40
Methylene Chloride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Disulfide	3.30	8.20	0.00	3.83	15.39	38.31	0.00	17.90	19.28
Chloroform	0.00	0.00	2.10	0.70	0.00	0.00	15.88	5.29	9.17
Toluene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6 summarizes the C_1 – C_4 gas results for the three test runs, along with the average concentrations and mass flow rates for the entire test period.

Table 6. C_1 – C_4 Gaseous Hydrocarbon Emissions.

	Measured Concentration (ppb)				Calculated Mass Flow Rate (g/hr)				
Compound Name	run #1	run #2	run #3	**AVG**	run #1	run #2	run #3	**AVG**	**SD**
Methane	2262.00	551.03	2444.00	1752.34	2222.40	542.51	2483.13	1749.35	1053.25
Ethane	4.42	0.00	7.97	4.13	8.14	0.00	15.17	7.77	7.59
Ethene	13.91	0.00	54.72	22.88	23.89	0.00	97.22	40.37	50.66
Propane	3.46	0.00	4.52	2.66	9.34	0.00	12.63	7.33	6.55
Propene	0.00	0.00	1.57	0.52	0.00	0.00	4.18	1.39	2.42
Butane	2.71	0.00	2.99	1.90	9.64	0.00	11.02	6.88	6.00
Ethyne	0.00	0.00	3.59	1.20	0.00	0.00	5.91	1.97	3.41
2M-Propene	0.00	0.00	6.32	2.11	0.00	0.00	22.45	7.48	12.96

5.0 TEST CRITIQUE

The testing and analyses were conducted without any major problems. The only significant concern at the Moss Landing Unit #1 facility is the accuracy of the flow rate measurement using the traverse sampling technique. As illustrated in Figure 5, the sampling location is a little over 2 stack diameters downstream of a 60-degree bend. Ideally, the sample location should be at least 8 stack diameters downstream of any flow disturbance to ensure fully developed, uniform flow. It is possible that the stack diameter that was traversed to determine average stack velocity is not representative of the actual average stack velocity. Additionally, there were only two sample ports available for the velocity traverse. This makes it difficult to confirm uniform flow, as a portion of the cross-sectional area is not measured. This should not have a significant effect on the pollutant concentrations measured, but may be a source of error when calculating mass flow rates.

One of the C_1-C_4 analyses (run #2) showed evidence of ambient contamination. Methane was the only hydrocarbon detected in this Tedlar bag sample, and the concentration was significantly lower than the other two samples. Tedlar bags are prone to miniscule punctures and tears, allowing some ambient air to mix with the sample. Future tests using this methodology should employ duplicate or triplicate concurrent bag tests.

6.0 REFERENCES

1. California Air Resources Board, *Methods 1, 2, 3, 4, 100*, *Source Testing Methods and Procedures*, 1999 Revision.

2. South Coast Air Quality Management District, M*ethod 5.1 – Determination of Particulate Matter from Stationary Sources*, SCAQMD Source Test Manual, 1997 Revision.

3. EPA 625/R-96/010b, *Compendium Method TO-11A, Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC) [Active Sampling Methodology],* January, 1999.

4. EPA 625/R-96/010b, *Compendium Method TO-14A, Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography,* January, 1999.

5. Siegl, W.O.; Richert, J.F.O.; Jensen, T.E.; Schuetzle, D.; Swarin, S.J.; Loo, J.F.; Prostak, A.; Nagy, D.; and Schlenker, A.M. (1993) Improved emissions speciation methodology for Phase II of the Auto/Oil Air Quality Improvement Research Program - Hydrocarbons and Oxygenates. Society of Automotive Engineers International Congress and Exposition Detroit, Michigan, March 1-5.

APPENDIX
Sampling/Analytical Data and Calculations